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published in
Osteoporosis International
2011

DOI (link to publisher)
10.1007/s00198-010-1279-1

document version
Publisher's PDF, also known as Version of record

citation for published version (APA)
van der Meer, I. M., Middelkoop, B. J. C., Boeke, A. J. P., & Lips, P. T. A. M. (2011). Prevalence of vitamin D deficiency among Turkish, Moroccan, Indian and sub-Sahara African populations in Europe and their countries of origin: an overview. *Osteoporosis International*, *22*(4), 1009-1021. https://doi.org/10.1007/s00198-010-1279-1

Osteoporos Int (2011) 22:1009–1021
DOI 10.1007/s00198-010-1279-1

REVIEW

Prevalence of vitamin D deficiency among Turkish, Moroccan, Indian and sub-Sahara African populations in Europe and their countries of origin: an overview

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Received: 25 February 2010 / Accepted: 7 April 2010 / Published online: 12 May 2010

Abstract
Summary Vitamin D status of nonwestern immigrants in Europe was poor. Vitamin D status of nonwestern populations in their countries of origin varied, being either similar to the immigrant populations in Europe or higher than in European indigenous populations. Vitamin D concentrations in nonwestern immigrant populations should be improved.
Purpose The higher the latitude, the less vitamin D is produced in the skin. Most European countries are located at higher latitudes than the countries of origin of their nonwestern immigrants. Our aim was to compare the serum 25-hydroxyvitamin D (25(OH)D) concentration of nonwestern immigrant populations with those of the population in their country of origin, and the indigenous population of the country they migrated to.
Methods We performed literature searches in the "PubMed" and "Embase" databases, restricted to 1990 and later. The search profile consisted of terms referring to vitamin D or vitamin D deficiency, prevalence or cross-sectional studies, and countries or ethnicity. Titles and abstracts were reviewed to identify studies on population-based mean serum 25(OH)D concentrations among Turkish, Moroccan, Indian, and sub-Sahara African populations in Europe, Turkey, Morocco, India, and sub-Sahara Africa.
Results The vitamin D status of immigrant populations in Europe was poor compared to the indigenous European populations. The vitamin D status of studied populations in Turkey and India varied and was either similar to the immigrant populations in Europe (low) or similar to or even higher than the indigenous European populations (high).
Conclusions In addition to observed negative consequences of low serum 25(OH)D concentrations among nonwestern populations, this overview indicates that vitamin D status in nonwestern immigrant populations should be improved. The most efficacious strategy should be the subject of further study.

Keywords Indian · Moroccan · Prevalence · Serum 25-hydroxyvitamin D · Sub-Sahara African · Turkish

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Introduction

Vitamin D status has been found to be poor among nonwestern immigrant populations in European countries compared to indigenous European populations [1–4]. The lower serum 25(OH)D concentrations among nonwestern immigrants compared to indigenous European populations may lead to differences in health. Consequences of vitamin D deficiency include bone- and muscle-related symptoms (e.g., bone and muscle pain), decreased muscle strength, and diseases (e.g., rickets in children; osteomalacia in adults) [5, 6]. Other possible consequences are diabetes mellitus, infectious diseases, and cancer [7].

Direct sunlight stimulates the production of vitamin D in the skin from 7-dehydrocholesterol. Other sources of vitamin D include some natural foods (e.g., fatty fish), fortified foods (e.g., margarine), and supplements. The amount of vitamin D produced through exposure to UVB radiation depends on skin type: the darker the skin, the more sunlight is required to produce a given amount of vitamin D [8–10]. Nonwestern immigrants usually have darker skin than indigenous European subjects. Therefore, they have a higher risk of lower serum 25-hydroxyvitamin D (25(OH)D) concentrations when living at the same latitude.

The duration of UVB irradiation needed to produce a certain quantity of vitamin D in a particular skin surface depends on season, time of day, and geographical location [11]. The higher the latitude, the lower the UVB intensity, and the fewer months and hours per day during which vitamin D is produced. Most European countries are located at a higher latitude than the countries of origin of nonwestern immigrants.

The threshold for vitamin D deficiency should—ideally—be based on its consequences. However, most studies of the consequences of vitamin D deficiency have been performed among older western populations in Europe and North America, rather than among adult nonwestern immigrant populations in these countries. Another means of establishing a deficiency threshold is through the use of reference values within a population [12]. For that purpose, a comparison of the vitamin D status of nonwestern immigrant populations with the populations in their countries of origin might be more suitable than a comparison with the indigenous western populations. Our aim was to compare the vitamin D status of nonwestern immigrant populations with both the populations in their countries of origin and the populations in the country they migrated to. Additionally, we wanted to identify what determinants were mentioned to explain differences in vitamin D status between subgroups in the studied populations.

Methods

We performed literature searches in the "PubMed" and "Embase" databases. The search profile consisted of terms referring to vitamin D or vitamin D deficiency, prevalence or cross-sectional studies, and countries or ethnicity. The search was restricted to publications from 1990 onwards; about 1,000 were returned. Titles and abstracts were reviewed to identify studies on population-based mean serum 25(OH)D concentrations among Turkish, Moroccan, Indian, and sub-Sahara African populations in Europe, Turkey, Morocco, India, or sub-Sahara Africa. We accepted the definitions of ethnicity as used in the identified articles.

We extracted data for the Turkish, Moroccan, Indian, and sub-Sahara African populations and for the indigenous European populations if this group was included in the studies performed in Europe. From suitable publications, we extracted information about geographical location and season of data collection, age and gender of the study population, duration of pregnancy if applicable, number of subjects, mean serum 25(OH)D concentration with standard deviation, percentage of subjects with serum 25(OH)D <25 nmol/l, and determinants of serum 25(OH)D concentration. Specific characteristics of the study population which could influence the vitamin D status, such as clothing habits, were also extracted. Of identified intervention studies, we used only data from baseline measurements. Serum 25(OH)D concentrations presented in nanogram per milliliter or microgram per liter were transformed into nanomole per liter. Data variances presented as standard errors or 95% confidence intervals were converted to standard deviations. When either vitamin D status parameter (mean and % <25 nmol/l) was not presented, another measure for vitamin D status (such as median concentration or % below another threshold) was extracted.

Results

Prevalence

The identified studies on Turkish populations in Europe are presented in Table 1 and on Turkish populations in Turkey in Table 2. The vitamin D status was lower in the Turkish groups in Europe than in the indigenous European groups. Vitamin D status in the Turkish groups in Turkey varied widely. The subgroups with covering clothes had the lowest serum 25(OH)D concentrations (mean 10 nmol/l) [13, 14]. Turkish elderly living in their own homes (mean 158 nmol/l for males and 103 nmol/l for females) and Turkish unveiled adult women (mean 135 nmol/l)—all of whom were measured at the end of summer—had the highest serum 25(OH)D concentrations [15, 16].

Studies on Moroccan populations in Europe are presented in Table 3. Table 4 presents the only study found on the vitamin D status of a Moroccan population in Morocco. As was the result among Turkish populations, the Moroccan populations in Europe had lower serum 25(OH)D concentrations than the indigenous European populations. The

Table 1 Studies among Turkish populations in Europe

Study	Study characteristics	Study population	Serum 25(OH)D (nmol/l) Mean±SD [a]	Determinants for lower serum 25(OH)D
Adults				
Madar et al. [39]	Norway, Oslo (60° N), all year round	Turkish F, mean 27 years (n=25)	26±14, 56% < 25	No daily use of vitamin D supplementation, education <10 years
Holvik et al. [33]	Norway, Oslo (60° N), in spring	Turkish M, mean 39 years for all men (n=87) Turkish F, mean 37 years for all women (n=101)	median 33, 23% < 25 median 26, 46% < 25	Female gender, younger age, April/May blood sample (compared to June), lower use of cod liver oil supplements, lower intake of fatty fish; in females: higher BMI, shorter educational length
Van der Meer et al. [1]	The Netherlands, Amsterdam, The Hague, Amersfoort, and Haarlem (52° N), all year round	Dutch M (40%)+F, median 45 years (n=102) Turkish M (41%)+F, median 35 years (n=121)	median 67, 06% < 25 median 27, 41% < 25	Autumn or winter season, pregnant or breastfeeding, lower consumption of fatty fish, no use of vitamin D supplements, smaller area of uncovered skin, no use of tanning bed, lower consumption of margarine, no preference for sun
Grootjans-Geerts and Wielders [25]	The Netherlands, Amersfoort, end of winter	Dutch F, mean 44 years (n=32) Turkish veiled F, mean 30 years (n=51)	28%<30 90%<30	–
Erkal et al. [2]	Germany, Giessen (50° N), end of winter	German M (50%)+F, 19–63 years (n=101) Turkish M, 18–69 years (n=270) Turkish F, 16–67 years (n=296)	29%<50 Median 40 Median 31	Female gender, veiling, having three or more children, living at higher latitude, higher BMI
Moreno-Reyes et al. [3]	Belgium, Brussels, all year round.	Belgian M (50%)+F, mean 52 years (n=100) Turkish M (50%)+F, mean 49 years, first-generation immigrants (n=101)	49±22, 13% < 25 31±20, 53% < 25	Winter season, male gender
Pregnant women				
Van der Meer et al. [26]	The Netherlands, The Hague (52° N), at the first antenatal visit (12th week), all year round	Western, mean 30 years (n=105) Turkish, mean 24 years (n=79)	53±22, 08% < 25 15±12, 84% < 25	–
Children				
Madar et al. [39]	Norway, Oslo (60° N), all year round	Turkish M+F, mean 7 weeks (n=25)	37±38, 56% < 25	Exclusively breastfed infants (no supplements)
Meulmeester et al. [27]	The Netherlands, The Hague, or Rotterdam, at the end of winter or the end of spring	Caucasian M (50%)+F, 8 years, The Hague, end of winter (n=39) Turkish M (50%)+F, 8 years, The Hague, end of winter (n=40) Caucasian M (50%)+F, 8 years, Rotterdam, end of spring (n=40) Turkish M (50%)+F, 8 years, Rotterdam, end of spring (n=40)	57±16 23±10 73±14 37±13	End of winter measurement, lower cumulative global sun radiation

SD standard deviation

[a] Unless mentioned otherwise

Table 2 Studies among Turkish populations in Turkey

Study	Study characteristics	Study population	Serum 25(OH)D (nmol/l) Mean±SD [a]	Determinants for lower serum 25(OH)D
Adults				
Erkal et al. [2]	Turkey, Mersin (36° N), Ankara (40° N), Istanbul and Unye (42° N), end of winter	Turkish M, 21–66 years (n=85)	Median 47	Female gender, veiling, having three or more children, living at higher latitude, higher BMI
		Turkish F, 17–69 years (n=242)	Median 36	
Guzel et al. [16]	Turkey (37º N), end of summer	Turkish F, mean 25 years, veiled (n=30)	83±40	Veiling, lower exposure to sunlight, longer duration of being veiled
		Turkish F, mean 25 years, unveiled (n=30)	135±68	
Alagol et al. [13]	Turkey, Istanbul (41° N), in summer	Turkish F, mean 24 years, dressed with usual areas exposed to the sun (n=18)	56±41	Covering clothes/veiling
		Turkish F, mean 28 years, traditional clothing, hands and face uncovered (n=15)	32±24	
		Turkish F, mean 26 years, traditional clothing, covering whole body including hands and face (n=15)	10±06	
Atli et al. [15]	Turkey, Ankara (40° N), at the end of summer	Turkish M, mean 73 years, own home (n=24)	158±108	Female gender, living in old age home, older age, lower benefit from ultraviolet index (ratio of points for sunlight exposure and covering clothes)
		Turkish F, mean 72 years, own home (n=171)	103±98	
		Turkish M, mean 76 years, old age home (n=87)	94±72	
		Turkish F, mean 75 years, old age home (n=138)	62±74	
Pregnant women				
Pehlivan et al. [14]	Turkey, Last trimester	Turkish, total group (n=78)	18±10, 80% < 25	Low educational level, insufficient intake of vitamin D within diet, “covered” dressing habits
		Turkish, with covered head and hands, not the face (n=4)	10±05	
		Turkish, with covered head, not the hands or face (n=49)	17±10	
		Turkish, with no cover on head, hands or face (n=25)	20±10	
Children				
Olmez et al. [34]	Turkey, Izmir, end of summer or end of winter	Turkish F, 14–18 years, low socioeconomic status, end of summer (n=32)	52±23	End of winter measurement, low socioeconomic status
		Turkish F, 14–18 years, high socioeconomic status, end of summer (n=32)	65±29	
		Turkish F, 14–18 years, low socioeconomic status, end of winter (n=30)	34±16	
		Turkish F, 14–18 years, high socioeconomic status, end of winter (n=30)	59±24	

SD standard deviation

[a] Unless mentioned otherwise

Table 3 Studies among Moroccan populations in Europe

Study	Study characteristics	Study population	Serum 25(OH)D (nmol/l) Mean±SD[a]	Determinants for lower serum 25(OH)D
Adults				
Van der Meer et al. [1]	The Netherlands, Amsterdam, The Hague, Amersfoort, and Haarlem (52° N)	Dutch M (40%)+F, median 45 years (n=102) Moroccan M (41%)+F, median 38 years (n=96) Median 30, 37% < 25	Median 67, 06% < 25	Autumn or winter season, pregnant or breastfeeding, lower consumption of fatty fish, no use of vitamin D supplements, smaller area of uncovered skin, no use of tanning bed, lower consumption of margarine, no preference for sun
Moreno-Reyes et al. [3]	Belgium, Brussels, all year round	Belgian M (50%)+F, mean 52 years (n=100) Moroccan M (50%)+F, mean 49 years, first-generation immigrants (n=100)	49±22, 13% < 25 27±17, 54% < 25	Winter season, male gender
Pregnant women				
Van der Meer et al. [26]	The Netherlands, The Hague (52° N), at the first antenatal visit (12th week)	Western, mean 30 years (n=105) Moroccan, mean 26 years (n=69)	53±22, 08% < 25 20±14, 81% < 25	–
Children				
Meulmeester et al. [27]	The Netherlands, The Hague or Rotterdam, at the end of winter or the end of spring	Caucasian M (50%)+F, 8 years, The Hague, end of winter (n=39) Moroccan M (50%)+F, 8 years, The Hague, end of winter (n=38) Caucasian M (50%)+F, 8 years, Rotterdam, end of spring (n=40) Moroccan M (50%)+F, 8 years, Rotterdam, end of spring (n=42)	57±16 30±14 73±14 38±14	End of winter measurement, lower cumulative global sun radiation

SD standard deviation

[a] Unless mentioned otherwise

Table 4 Studies among Moroccan populations in Morocco

Study	Study characteristics	Study population	Serum 25(OH)D (nmol/l) Mean±SD [a]	Determinants for lower serum 25(OH)D
Adults				
Allali et al. [17]	Morocco, Rabat, in the end of winter	Moroccan F, mean 50 years, total group (n=415)	45±20	Age>55 years, calcium intake<700 mg/d, wearing a veil, sunlight exposure<30 min/day
		Moroccan F, mean 43 years, premenopausal (n=108)	47±19	
		Moroccan F, mean 56 years, postmenopausal (n=307)	44±20	

SD standard deviation

[a] Unless mentioned otherwise

Moroccan adult women in Morocco, who were measured at the end of winter, had a mean serum 25(OH)D concentration of 45 nmol/l [17]. This was lower than the indigenous population in the Netherlands (median 67 nmol/l) and in Belgium (mean 49 nmol/l) [1, 3]. The Dutch and Belgian populations consisted of both men and women, and these were measured year-round, which might explain the difference.

Studies on adult Indian (or South Asian) populations in Europe also found lower serum 25(OH)D concentrations in comparison to indigenous European populations (Table 5). Concerning pregnant women and children, we did not identify any studies which included an indigenous European population. The vitamin D status among various Indian populations in India differed (Table 6). Some populations with limited sunlight exposure, such as physicians and nurses (mean 8 nmol/l in winter and 18 nmol/l in summer) or Delhi-based males (mean 18 nmol/l) and females (mean 17 nmol/l) measured in winter, had low serum 25(OH)D concentrations, similar to Indian populations in Europe [18, 19]. Other, mainly rural, Indian adult populations in India had higher serum 25(OH)D concentrations [20, 21].

Sub-Saharan Africans in the Netherlands—consisting predominantly of Ghanaians and Somalis—had a median serum 25(OH)D concentration of 33 nmol/l (n=57) [1]. Congolese immigrants in Belgium had a mean serum 25 (OH)D concentration of 38 nmol/l (standard deviation (SD) of 14 nmol/l). We did not identify any studies on vitamin D status in Ghana, Somalia, or the Democratic Republic of Congo. Studies in sub-Saharan countries include a study in Cameroon, with a mean serum 25(OH)D concentration of 53 nmol/l (SD 19 nmol/l) among an older population (aged 60–86 years), a study on Nigerian children (6–35 months) with a mean serum 25(OH)D concentration of 64 nmol/l (sd 23 nmol/l), and a study on Gambian women aged 25 or older, with a mean serum 25(OH)D concentration between 73 nmol/l (SD 20 nmol/l) and 113 nmol/l (SD 27 nmol/l), varying with age [22–24].

In all studies performed in Europe where both groups were included, immigrant groups in European countries had significantly lower serum 25(OH)D concentrations than indigenous European groups [1–4, 25–32].

Determinants

In the last column of each table, the determinants for a lower 25(OH)D concentration are presented. As expected, many studies found a lower exposure to sunlight (e.g., behavior or season) [1–3, 13–18, 27, 32–38] or a restricted intake of vitamin D (via food or supplements) [1, 14, 17, 33, 39, 40], to be associated with a lower serum 25(OH)D concentration.

Neither gender nor age were unambiguously associated with the serum 25(OH)D concentration. Female gender was found to be a determinant for a low serum 25(OH)D concentration [2, 4, 15, 33, 35, 36, 41, 42], but not in all studies that compared males and females [3, 19, 20, 31, 41, 43]. Both a younger age [33] and an older age [15, 17] were associated with a lower serum 25(OH)D concentration.

Other determinants of lower serum 25(OH)D concentrations—explained by association with exposure to sunlight or dietary habits—are a lower socioeconomic position [34, 42], a shorter duration of education [33, 39], or a lower educational level [14], living in an urban environment [20, 21], and an earlier start time to the workday [44].

In newborn children, a mother's lower serum 25(OH)D concentration was associated with a lower serum 25(OH)D concentration in the child [18, 45, 46].

Discussion

The vitamin D status of Turkish, Moroccan, Indian, and sub-Sahara African immigrant populations in Europe was poor compared to the indigenous European populations. The vitamin D states of studied populations in Turkey, Morocco, and India varied between concentrations similar

Table 5 Studies among Indian populations in Europe

Study	Study characteristics	Study population	Serum 25(OH)D (nmol/l) Mean±SD [a]	Determinants for lower serum 25(OH)D
Adults				
Brooke-Wavell et al. [28]	United Kingdom	White European F, mean 59 years (n=23) South Asian F, mean 59 years (Bangladeshi, Indian n=24)	76±18 33±13	–
Ward et al. [29]	United Kingdom, Manchester	White Caucasian European F, mean 30 years (n=96) Pakistani muslim or Gujarati Hindu F, mean 29 years (n=95)	67±34 20±12	–
Ford et al. [4]	United Kingdom, Birmingham, end of summer.	Caucasian M+F, mean 59 years (1–92 years; n=317) Asian M+F, mean 47 years (2–87years) (n=251)	58±31, 12% < 25 36±26, 31% < 25	In the Asian group: female gender
Hamson et al. [30]	United Kingdom, Leicester	White M, 33 years (n=37) White F, 32 years (n=51)	3% < 12.5 0% < 12.5	–
		Gujarati M, 34 years (Gujarat region India; n=42)	60% < 12.5	
		Gujarati F, 34 years (Gujarat region India; n=71)	51% < 12.5	
Solanki et al. [31]	United Kingdom, Birmingham, end of winter.	White M, <65 years, mean 30 years men and women (n=4) White F, <65 years, mean 30 years men and women (n=12)	28±12 48±29	–
		White M, >65 years, mean 74 years men and women (n=4)	55±14	
		White F, >65 years, mean 74 years men and women (n=14)	40±21	
		Asian M, <65 years, mean 31 years men and women (n=14)	16±08	
		Asian F, <65 years, mean 31 years men and women (n=3)	21±07	
		Asian M, >65 years, mean 72 years men and women (n=21)	13±09	
		Asian F, >65 years, mean 72 years men and women (n=16)	23±20	
Finch et al. [32]	United Kingdom, London, all year round.	White M (50%)+F, mean 39 years, winter (n=30) White M (50%)+F, mean 39 years, summer (n=18)	39±18 65±27	Winter season (March/April), vegetarian, Hindu religion, Muslim religion (only in winter); Hindus seasonal responses are blunted, resulting in significantly lower peak values than for whites or non-vegetarian (Muslim) Asians
		Asian M (70%)+F, mean 42 years, non-vegetarians, winter (n=116)	19±13	
		Asian M (70%)+F, mean 42 years, non-vegetarians, summer (n=22)	45±24	
		Asian M (40%)+F, mean 42 years, vegetarians, winter (n=29)	10±8	
		Asian M (40%)+F, mean 42 years, vegetarians, summer (n=16)	27±21	
Van der Meer et al. [1]	The Netherlands, Amsterdam, The Hague, Amersfoort and Haarlem (52°N)	Dutch M (40%)+F, median 45 years (n=102) Surinam South Asian M (37%)+F, median 41 years (n=107)	Median 67, 06% < 25 Median 24, 51% < 25	Autumn or winter season, pregnant or breastfeeding, lower consumption of fatty fish, no use of vitamin D supplements, smaller area of uncovered skin, no use of tanning bed, lower consumption of margarine, no preference for sun
Pregnant women				
Datta et al. [63]	United Kingdom, Cardiff (51.5°N), at booking visit	Indian subcontinent (n=100)	52% < 20	Being in Britain for more than 3 years (compared to less than 3 years and to being born in Britain)
Children				
Lawson and Thomas [40]	UK, autumn	Bangladeshi M+F, 2 years (n=139) Pakistani M+F, 2 years (n=200)	42±21, 20% < 25 36±20, 34% < 25	Failure to take a vitamin supplement.
		Indian M+F, 2 years (n=279)	42±23, 25% < 25	
Koch and Burmeister [64]	Germany, in summer	Asian M (33%)+F, 3–17 years (Birma, Sri Lanka, India; n=9)	28±09, 44% < 25	–

SD standard deviation

[a] Unless mentioned otherwise

Table 6 Studies among Indian populations in India

Study	Study characteristics	Study population	Serum 25(OH)D (nmol/l) Mean±SD [a]	Determinants for lower serum 25(OH)D
Adults				
Goswami et al. [19]	India, Delhi, in winter	Adult M, mean 31 years (n=244)	18±9	–
		Adult F, mean 35 years (n=398)	17±11	
Goswami et al. [41]	India, Agota village (29° N), in winter	Adult M, rural, mean 43 years (n=32)	44±24	Female gender
		Adult F, rural, mean 43 years (n=25)	27±16	
Harinarayan et al. [20]	India, Tirupati (13° N)	Adult M, urban, mean 46 years for urban M+F (n=134)	46±22	Urban subject
		Adult M, urban, mean 43 years for urban M+F (n=109)	59±20	
		Adult F, urban, mean 46 years for urban M+F (n=807)	39±20	
		Adult F, rural, mean 43 years for rural M+F (n=96)	48±22	
Zargar et al. [35]	India, Kashmir valley, all year round	Indian M, mean 29 years (n=64)	38±30, 41% < 25	Lower exposure to sunlight, female gender
		Indian F, mean 27 years (n=28)	14±11, 96% < 25	
Gulvady et al. [44]	India, Mumbai	Indian M, 40–68 years, senior executives (indoor workers; n=86)	28% < 19	Earlier start of the workday
Vupputuri et al. [43]	India, Delhi (28° N)	Asian Indian M, mean 43 years (for both men and women), urban, middle income, mostly working indoors (n=51)	27±17	–
		Asian Indian F, mean 43 years (for both men and women), urban, middle income, mostly housewives (n=54)	22±12	
Harinarayan [65]	India, Tirupati (13° N), all year round	Indian F, mean 54 years, postmenopausal (n=164)	37±18, 30% < 25	Higher dietary calcium intake, higher dietary phytate intake, higher phytate to calcium ratio
Harinarayan et al. [21]	India, around Tirupati (13° N), winter to summer (Jan–Jul)	Indian, mean 44 years, rural (n=191)	53±06, 03% < 25	Urban subject, lower dietary calcium intake, higher phytate to calcium ratio
		Indian, mean 46 years, urban (n=125)	34±07, 35% < 25	
Goswami et al. [18]	India, Dehli (28° N), in winter or summer	Indian M, mean 25 years, soldiers, winter (n=31)	47±12	Less exposure to sunlight, more skin pigmentation, winter season
		Indian M (58%)+F, mean 23 years, physicians and nurses, winter (n=19)	08±03	
		Indian M (67%)+F, mean 43 years, depigmented persons, winter (n=15)	18±11	
		Indian M (58%)+F, mean 24 years, physicians and nurses, summer (n=19)	18±08	
Pregnant women				
Sahu et al. [36]	India, Barabanki district, 32 km from Lucknow (27°), all year round	Indian, rural, mean 27 years (n=139)	38±20, 32% < 25	Lower summer sun exposure, measurement in winter
Farrant et al. [66]	India, Mysore (South India) at the 30th week of pregnancy	Indian, mean 24 years (n=559)	Median 38, 31% < 28 nmol/l	Taking calcium and vitamin D at recruitment, measurement in Mar–Aug
Bhalala et al. [45]	Western India, at the 37th week of pregnancy, all year round	Indian, 20–35 years, middle income group (n=42)	57±27	Lower serum 25(OH)D in mother→ lower serum 25(OH)D in cord blood
		Cord blood (n=42)	48±24	
Sachan et al. [46]	India, Lucknow (27° N), before labor, autumn	Indian, total group (n=207)	43% < 25	–
		Indian, urban (n=140)	35±24	
		Indian, rural (n=67)	35±22	
Goswami et al. [18]	India, Dehli (28° N), in summer	Indian, mean 23 years, poor socioeconomic class (n=29)	22±11	–
Children				
Sahu et al. [36]	India, Barabanki district, 32 km from Lucknow (27° N), all year round	Indian F, rural, mean 14 years, total group (n=121)	33±16, 34% < 25	Lower summer sun exposure, female gender, measurement in winter
		Indian M, mean 14 years, brothers of the 28 girls, in winter (n=34)	68±29, 36% < 25	

		Indian F, mean 14 years, sisters of the 34 boys, in winter (n=28)	31±14, 03% < 25	
Puri et al. [37]	India, Dehli (28° N), in summer	Indian F, mean 12 years (6–18), lower socioeconomic strata (n=193)	35±17, 31% < 25	Higher BMI, lower sun exposure, smaller percentage of body surface area exposed
		Indian F, mean 12 years (6–18), upper socioeconomic strata (n=211)	29±13, 39% < 25	
Harinarayan et al. [20]	India, Tirupati (13° N)	Indian M, urban, mean 13 years for urban M+F (n=30)	39±17	–
		Indian M, rural, mean 13 years for rural M+F (n=34)	43±22	
		Indian F, urban, mean 13 years for urban M+F (n=39)	46±28	
		Indian F, rural, mean 13 years for rural M+F (n=36)	48±23	
Bhalala et al. [45]	Western India, all year round	Indian, 3 months, exclusively breast fed, from middle income mothers (n=35)	45±24	Lower serum 25(OH)D in mother
Khadilkar et al. [67]	India, Pune (18° N), in winter	Post-menarchal F, mean 15 years (n=50)	70%<30	–
Sivakumar et al. [68, 69]	India, Hyderabad, end of winter, summer (Mar and Jul)	Indian, M+F, 6–18 years, middle income, semi-urban (n=328)	26% < 25	–
Marwaha et al. [42]	India, New Dehli (28° N)	Indian M, 10–18 years (n=325)	27% < 22.5	Female gender, lower socioeconomic status
		Indian F, 10–18 years (n=435)	42% < 22.5	
		Indian M (39%)+F, 10–18 years, low socioeconomic group (n=430)	42% < 22.5	
		Indian M (48%)+F, 10–18 years, upper socioeconomic group (n=330)	27% < 22.5	
Sachan et al. [46]	India, Lucknow (27° N), autumn	Indian neonates (cord blood, n=207)	21±14	Lower serum 25(OH)D in mother
Tiwari and Puliyel [70]	India, Dehli, in winter or summer	9–30 months, Sundernagari area, winter (n=47)	96±26	–
		9–30 months, Rajiv Colony area, winter (n=49)	24±27	
		9–30 months, Rajiv Colony area, summer (n=48)	18±22	
		9–30 months, Gurgaon area, summer (n=52)	19±20	
Agarwal et al. [38]	India, Dehli (28° N), end of winter	Mean 16 months (9–24), Mori Gate area (high pollution; n=26)	31±18	Atmospheric pollution
		Mean 16 months (9–24), Gurgaon area (low pollution; n=31)	68±18	
Goswami et al. [18]	India, Dehli (28° N), in summer	Indian M (55%)+F, newborns from mothers from poor socioeconomic class (n=29) Cord blood	17±05	Lower serum 25(OH)D in mother

SD standard deviation

[a] Unless mentioned otherwise

to the immigrant populations in Europe (low) and concentrations similar to or higher than the European indigenous populations (high). Determinants of the serum 25(OH)D concentration included both sources of vitamin D: exposure to sunlight and intake of vitamin D.

Gender and age were each associated with serum 25 (OH)D concentration in both directions. Differences according to gender and age group could be the result of biological differences but might also reflect behavioral differences; dress style (e.g., wearing a veil) is often mentioned as a reason for a higher prevalence of vitamin D deficiency among women than men. A lower serum 25 (OH)D concentration among older participants can partly be the result of the lower capacity of the skin to produce vitamin D after exposure to sunlight. The study that found lower serum 25(OH)D concentrations at younger ages [33] might have had a study population that was too young to find an effect of a lower skin capacity (their mean age was below 40 years).

As the described studies were observational, not all determinants could be studied due to a lack of variation in the determinants. For instance, Sahu et al. described the dietary intake in rural India as remarkably monotonous from meal to meal, with a low consumption of dairy and foods containing reasonable amounts of vitamin D [36]. As a consequence, it is difficult to find an association between dietary intake and serum 25(OH)D.

The darker skin types of the immigrant populations are a suitable protection against the intensity and amount of sunlight in their countries of origin, while they are a risk factor for vitamin D deficiency in northerly European countries. The serum 25(OH)D concentrations of the populations in the country of origin may, therefore, indicate normal or reference concentrations. However, those populations may themselves be deficient or suffer from insufficient concentrations as a whole. Given that until recently, mankind lived and worked outside, the serum 25(OH)D concentrations of groups who currently spend much of their time outdoors might, therefore, be considered "normal" [47]. Serum 25(OH)D concentrations of rural populations, who are expected to have a greater exposure to sunlight as a result of their agricultural occupation than urban populations [20, 21], might be a more suitable indicator of normal concentrations than those of total populations.

The high (>100 nmol/l) serum 25(OH)D concentrations in subgroups of two Turkish studies, which were performed at the end of the summer, suggest a large impact of sunlight. As sun exposure does not lead to toxic vitamin D concentrations due to a feedback mechanism, these serum 25(OH)D concentrations are expected to be within the normal or reference range, which is an additional argument that the low serum 25(OH)D concentrations (found in immigrant populations) can be interpreted as a deficiency. Of course, assay differences might also explain part of the difference with other studies.

Symptomatic vitamin D deficiency is also suggested by the prevalence of rickets in Turkey, India, and some African countries [48–53]. The incidence of rickets in Eastern Turkey declined from 6.09% to 0.099% after a nationwide free vitamin D supplementation program [54]. Within European countries, rickets is not highly prevalent, but immigrant populations are groups at risk [55–57]. Additionally, although most nonwestern immigrant populations are younger than the indigenous European populations, cases of osteomalacia in nonwestern immigrants have been observed [58, 59]. Finch et al. found all but one case of osteomalacia within the vegetarian Asian group in England, the group with lowest vitamin D concentrations in their study [32]. Furthermore, osteoporotic and peripheral fractures were found in the vitamin-D-deficient subgroup in Morocco [17]. Erkal et al. found that 61% of the Turkish group (in Turkey) and 55% of the Turkish immigrant group in Germany complained of bone pain and/or nonspecific generalized muscle aches and pain, while it was 15% within the German group with higher serum 25(OH)D concentrations [2]. However, one should keep in mind that serum 25(OH)D is not the sole determinant of rickets; calcium intake is also important [48, 60, 61].

The comparison of serum 25(OH)D concentrations of the various populations in this article has some limitations.

First, several studies present the prevalence of vitamin D deficiency but have excluded individuals using drugs or medication known to affect bone metabolism, those recently treated for vitamin D deficiency, or those who used vitamin D supplements [1, 2, 4, 14–17, 19, 28, 35, 37, 41–43]. Medications that affect bone metabolism include, among others, vitamin D and calcium. One can argue whether the presented values represent the real prevalence in the respective populations when these individuals are excluded. However, we expect the number of excluded individuals to be small and, therefore, not of great influence on the prevalence. Furthermore, it implies that the prevalence is applicable for an apparently healthy population.

Second, the season of blood sampling varies, and this might account for a part of the observed differences between studies, because the intensity of sunlight and the amount of sunlight per day varies between seasons. These differences may be larger when studies in European countries are part of the comparison, because seasonal differences in sunlight are expected to be higher in countries at higher latitudes. For that reason, the time of year was mentioned in the tables.

Third, the comparison is hampered because the serum 25 (OH)D assessment methods differ, which may influence differences between groups [62]. In addition, the level of accuracy of studies within Europe and in the country of origin might differ. However, although we could not adjust for this type of bias, we presume that the differences will not be systematic or large enough to substantially alter the conclusions.

Finally, in comparing the various populations, it is important to realize that the social conditions of the immigrants might not be the same as those of the original populations. The cultural habits (skin-covering clothes, sun exposure, diet) might also change after immigration, particularly among the second generation.

Serum 25(OH)D concentrations of nonwestern immigrants in Europe and of subgroups of Turkish, Moroccan, Indian, and sub-Saharan countries are low. Ways to increase the serum 25(OH)D concentration include increased exposure to sunlight and increased intake of products that contain vitamin D. The strategy to effectuate these increases will differ in the various countries and populations and should be the subject of further study. These studies should ideally include measures of health to support the need for this increase in serum 25(OH)D.

Acknowledgement We gratefully acknowledge René Otten of the VU University Medical Library for his assistance in searching the PubMed and Embase databases.

Conflicts of interest None

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